displays. In general terms, Braille cells according to the present invention utilize cylinders, with each one of the cylinders corresponding to one of the dots in a Braille cell. Typical Braille cells contain six or eight dots arrayed in two columns. Each of the cylinders can be filled with a medium that expands under heat. Each of these cylinders further comprises a mechanism for applying heat to the medium, causing the medium to expand. Each of the cylinders also has a flexible material that deforms as the medium expands, with the flexible material forming a bump. This bump serves as one of the dots in a refreshable Braille cell. To form a particular Braille character, the desired ones of the six (or eight) dots in a Braille cell can be actuated by applying heat to medium in the desired cylinders. When the next character is to be displayed, heat can be applied to the desired cylinders to form the dots of that character.

[0023] A typical Braille display according to the present invention comprises a number of refreshable Braille cells arranged in one or more rows. Braille display systems can be used in any type of device that can be or is touched by the hand, and can be made to communicate or display tactily. The present invention is particularly adapted for use in computer displays, with the Braille cells being actuated under software control to communicate information through the Braille cells. As further described below, however, the refreshable Braille cells and display system according to the present invention can be used in many different applications beyond computer displays.

[0024] It will be understood that in describing the present invention, when an element or layer is referred to as being "on", "connected to", "coupled to" or "in contact with" another element or layer, it can be directly on, connected or coupled to, or in contact with the other element or layer or intervening elements or layers may be present. In contrast, when an element is referred to as being "directly on,""directly connected to", "directly coupled to" or "directly in contact with" another element or layer, there are no intervening elements or layers present. Likewise, when a first element or layer is referred to as being "in electrical contact with" or "electrically coupled to" a second element or layer, there is an electrical path that permits current flow between the first element or layer and the second element or layer. The electrical path may include capacitors, coupled inductors, and/or other elements that permit current flow even without direct contact between conductive elements.

[0025] It will also be understood that, although the terms first, second, etc. may be used herein to describe various elements, components, regions, layers and/or sections, these elements, components, regions, layers and/or sections should not be limited by these terms. These terms are only used to distinguish one element, component, region, layer or section from another region, layer or section. Thus, a first element, component, region, layer or section without departing from the teachings of the present invention.

[0026] FIG. **1** shows one embodiment cylinder **10** that can be used in a Braille cell according to the present invention that can be combined with five (or seven) other similar cylinders to form a Braille cell. The cylinder comprises a cylinder housing **12** and a flexible membrane **14** over one open end of the cylinder housing **12**. The flexible membrane **14** forms one of the dots of a Braille cell. The flexible membrane **14** can be made of many different materials but is preferably made of material having a low modulus of elasticity.

[0027] The cylinder **10** further comprises a heating mechanism **16**, and in different embodiments according to the present invention, the heating mechanism **16** can be arranged in many different locations on the inside or outside of the cylinder housing **12**. In the embodiment shown, the heating mechanism **16** is arranged in the opening of the cylinder housing **12** opposite the membrane **14**. Many different heating mechanisms can be used, with a suitable heating mechanism **16** as shown being microheater on a substrate. The heating mechanism **16** generates heat in response to an electrical signal, with the substrate containing structures, such as conductive traces, that conduct an electrical signal to the microheater. The microheater may be similar to that described in the following publications that are hereby incorporated herein by reference: Grosjean et al., A Thermodynamic Microfluid System [Conference Paper], *Technical Digest, MEMS* 2002 *IEEE International Conference, Fifteenth IEEE International Conference on Micro Electro Mechanical Systems* (Cat. No. 02CH37266) IEEE 2002, pp. 24-27, Piscataway, N.J., USA; and Grosjean et al., Micro Balloon Actuators For Aerodynamic Control [Conference Paper]*Proceedings MEMS* 98, *IEEE Eleventh Annual International Workshop on Micro Electro Mechanical Systems, In Investigation of Micro Structures, Sensors, Actuators, Machines and Systems* (Cat. No. 98CH36176), IEEE, 1998, pp. 166-71, New York, N.Y., USA.

[0028] The cylinder housing **12** is at least partially filled with a medium **16** that expands under heat, such as a gas or a liquid, although it is understood that different materials can be used and that different combinations of materials can be used. When an electrical signal is provided to the heating mechanism **16**, it heats the medium causing it to expand within the cylinder housing **12**. All surfaces of the cylinder **10** contacting the medium are rigid except for the flexible membrane **14**, such that the expanding medium causes the membrane **14** to bulge. This bulge serves as an actuated dot of the Braille cell.

[0029] When the electrical signal is removed from the heating mechanism **16**, the medium **18** cools and contracts, and the membrane returns to its original position. The expansion **1** and contraction of the medium allows for the cylinder **10** and its Braille cell to be "refreshed". This expansion and contraction of the medium under an electrical signal that causes heat, gives the cylinder **10** its electrothermal characteristics.

[0030] FIG. **2** shows first and second cylinders **32**, **34** in one embodiment of a Braille cell **30** according to the present invention. The Braille cell also contains either an additional four or six cylinders, as the case may be, to form a complete Braille cell. Each of the cylinders is defined by a chamber wall **36**, a membrane **38** and an microheater **40**. The cylinders are arranged on a substrate **42** with each microheater **40** on the substrate at the base of the cylinder, and the chamber walls **36** bonded to the substrate **42**. The microheater generates heat in response to an electrical signal and is preferably an electrode deposited on the substrate using known deposition methods such as sputtering, E-beam evaporation, or lift-off methods. In the lift-off method lithography is used to provide a pattern that is the reverse of the electrode